



VZLUSAT-2: CubeSat with Linux Payload Computers

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Outline

- Introduction
- VZLUSAT-2
 - Hardware
 - Software
 - Operating
- Questions

Takeaway



- What are the specifics of the COTS (Commercial off-the-shelf) components based Linux computer in space?
- How the Linux computer may be operated in space?
- Our future plans.

Czech Aerospace Research Centre (VZLÚ)



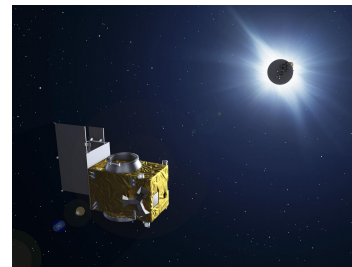
- Research organization established in 1922 for aviation
- Space activities since 2003
- ~200 employees, based in Prague and Brno, Czech Republic
- A few examples of space subcontracts:



SWARM (ESA)



X-ray telescope
(Penn State/NASA)

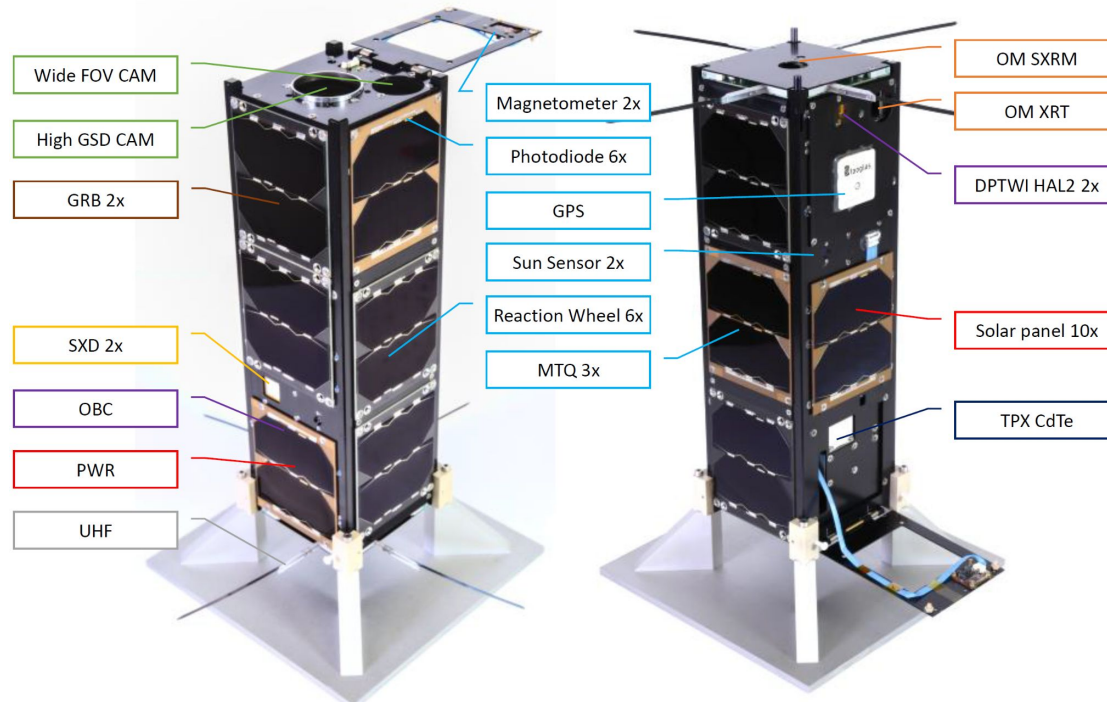


Proba-3 (ESA)



Ariane 6 (ESA)

VZLUSAT-2 – overview



- 3U CubeSat (10 x 10 x 34 cm)
- Staff: VZLU 28 + ~70 external
- Six scientific payloads
- EO – primary mission
 - BW high GSD ~25 m/px
 - RGB wide FOV ~500 m/px
- UHF radio Rx/Tx
- ADCS (attitude control)
 - 3-axis magnetorquer
 - 6x reaction wheel
 - 2x Sun sensor, gyro
- Sun-synchronous orbit
 - ~530 km altitude (LEO)
 - ~7.6 km/s speed
 - ~95 min period
- Launch
 - January 13, 2022
 - Falcon 9 (Transporter-3 mission)
 - Cape Canaveral

VZLUSAT-2 – system description



- Communication scheme

- CubeSat Space Protocol
- CAN, I²C

- Main platform limitations

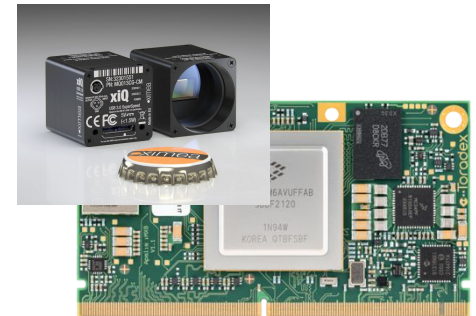
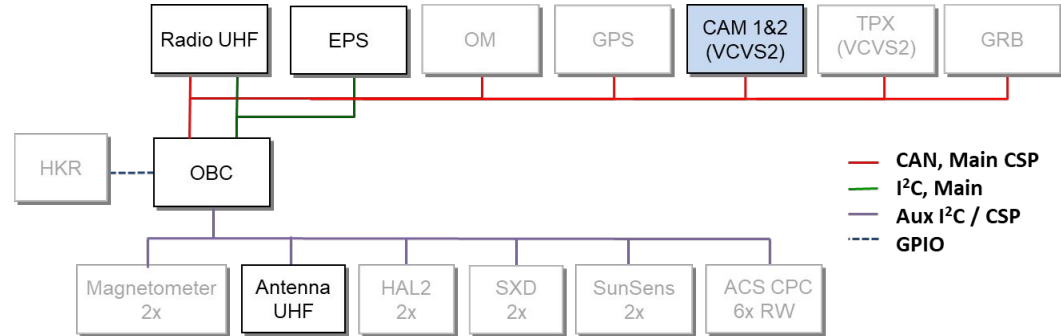
- Power budget (<3 W)
- Link budget (<9.6 kb/s)
- Delivery time (<8 months)

- Camera basic requirements

- High sampling rate (COTS camera with USB 3.0, PCIe, other?)
- Image previews (compression)
- Versatility, in-orbit extendability

- X-ray optical payload requirements

- Computer with USB 2.0

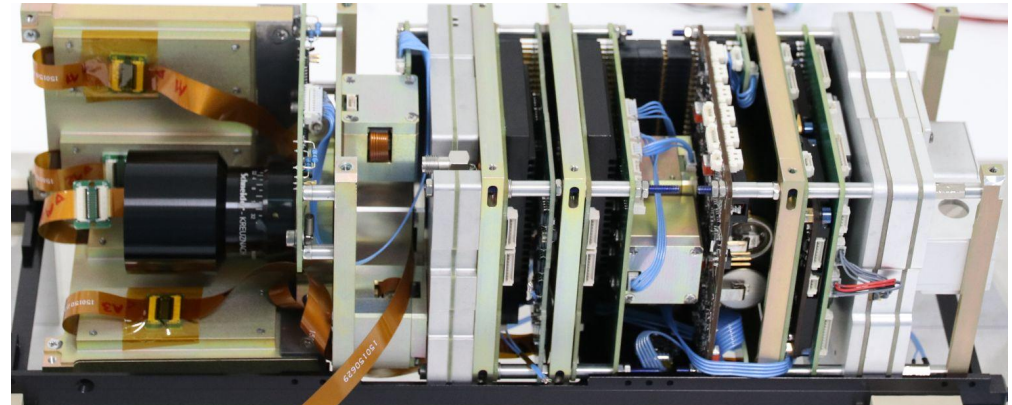
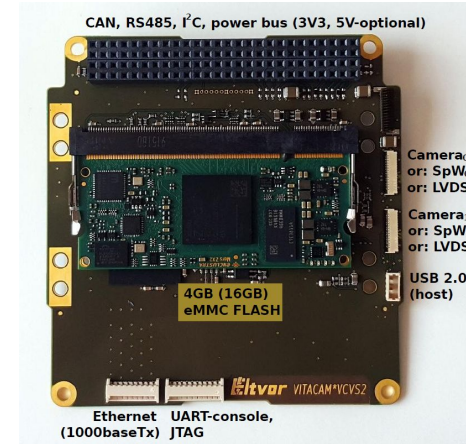


Payload computers – overview



2x VCVS2 computer (by Eltvor)

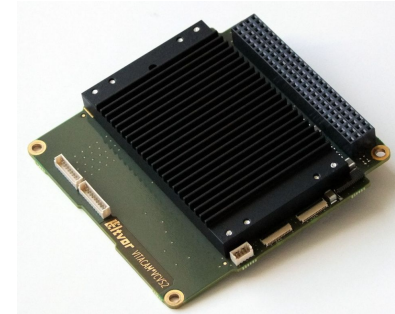
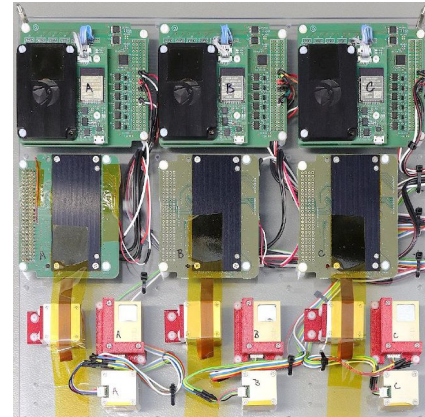
- PC/104 stack: 89 x 92 mm
- Xilinx Zynq-7010
 - ARM® dual-core Cortex™-A9
 - Xilinx Artix™-7 28 nm FPGA fabric
- LVDS (14 pairs in total), e.g.:
 - 1x BW and 1x RGB (Bayer)
 - Each 1.3 Mpix
- Serial interfaces
 - CAN, up to 1 Mb/s
 - USB 2.0 host
- 4GB eMMC
- Power switches
 - eMMC
 - Both cameras



Hardware considerations – Low Earth orbit 1/2



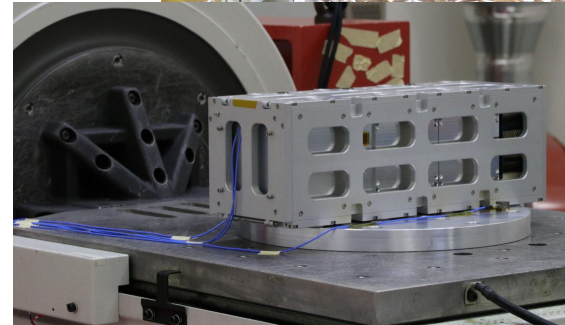
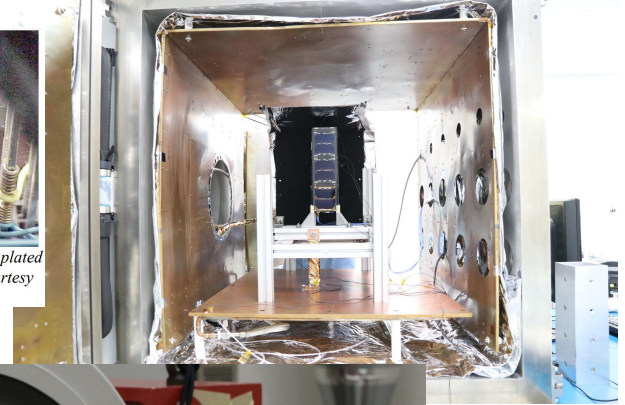
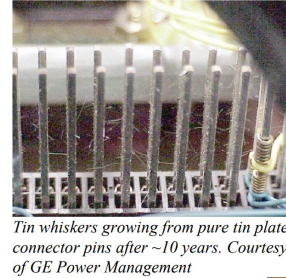
- Cumulative long-term ionizing (TID)
 - e.g., increased leakage
 - Aluminium shielding
 - TID tests, e.g. Co-60 source, 40krad @400hours
- High energy protons >200MeV (SEE)
 - Single Event Upsets (SEUs). Soft errors, non-destructive, e.g., bitflips in memory cells.
 - ECC memories
 - Single Event Latch-up (SEL). Results in a high operating current, a power reset is required.
 - RadHard components (very expensive)
 - Latch-up protection, circuit breaker



Hardware considerations – Low Earth orbit 2/2



- Low pressure
 - Outgassing
 - Low outgassing materials
 - Tin whiskers
 - Avoid lead-free soldering, e.g. BGA PbSn reballing
 - PCB coating (low outgassing)
- Thermal cycling from -40°C to 50°C
 - Tests in thermal-vacuum chamber
- Mechanical testing
 - Static, sine, random, shock vibration
 - Random load of overall level of 14.1 Grms
- COTS
 - Automotive grade, qualified for
 - Temperature resistance
 - Mechanical shock and vibration



BSP and software

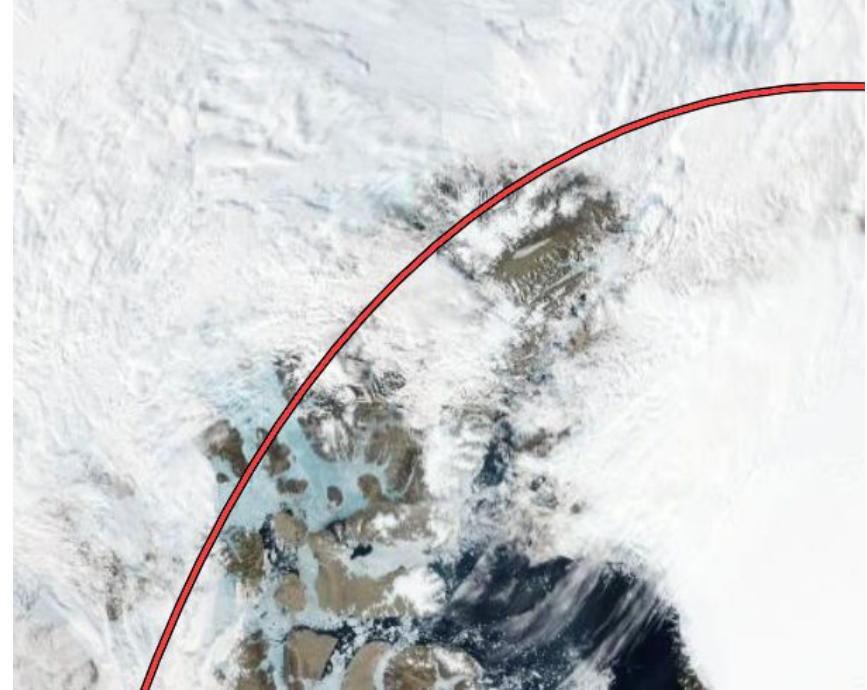


- Built by Enclustra Build Environment
- Boot: automatic selection of images in U-Boot, no supervisor
- rootfs in RAM, eMMC mounted when needed
- Debugging: no JTAG, no serial console, only power cycle and shell over CSP
- On-board communication: [SocketCAN](#), [libcsp](#)
- Image compression: [OpenJPEG](#)
- X-ray optical payload control software is on [gitlab](#)
- Our terminal client vcom

Unplanned in-orbit upgrade



- [Zaitra](#) was interested to test their AI classifier (cloud detection).
- The binary was uploaded and run on the camera computer.
- Upload of 112kB: 10 passes, 27 hours. 21kB was uploaded during the best pass.
- Cloudy weather →

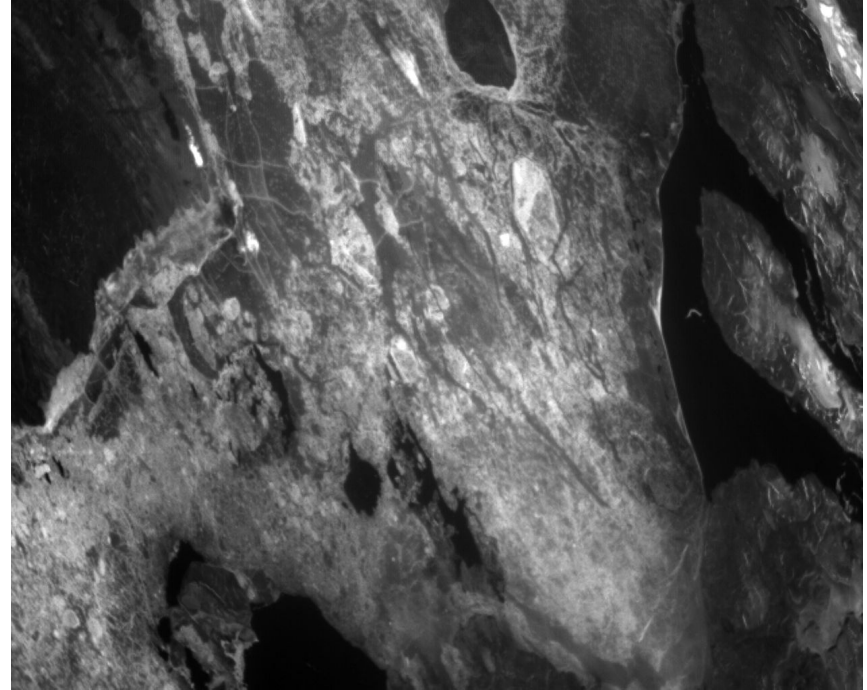


Clouds near Greenland (source: [Zoom Earth](#))

Unplanned in-orbit upgrade



- [Zaitra](#) was interested to test their AI classifier (cloud detection).
- The binary was uploaded and run on the camera computer.
- Upload of 112kB: 10 passes, 27 hours. 21kB was uploaded during the best pass.
- The selected high-scored picture →



Area near Greenland without clouds

VZLUSAT-2 – operation



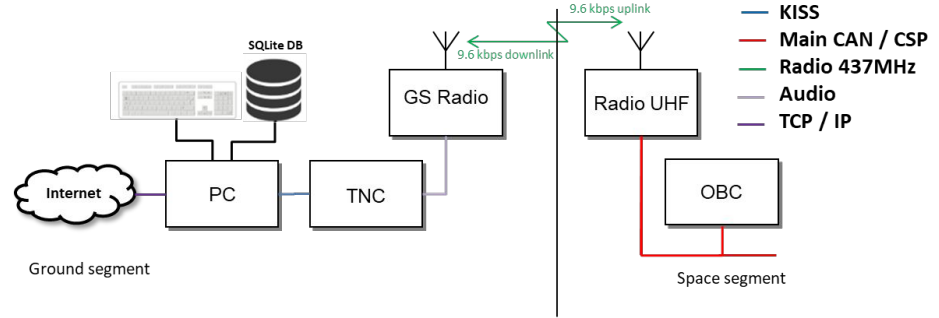
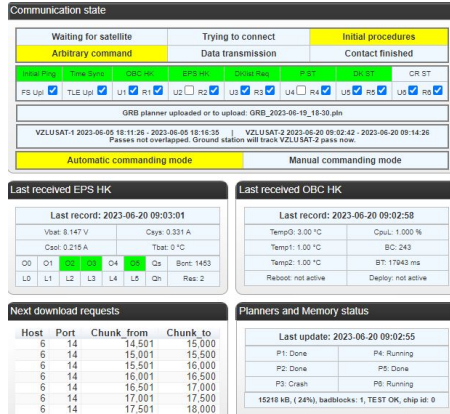
- 5-6 contacts per day, <1 hour in total

Future pass prediction of VZLUSAT-2 for Pilsen station

AoS	Duration	Max_elev
2023-06-21 10:21:09	662	24
2023-06-21 11:57:08	279	2
2023-06-21 18:01:06	343	3
2023-06-21 19:31:03	678	29
2023-06-21 21:05:01	681	27
2023-06-22 08:31:24	660	22
2023-06-22 10:05:18	685	34
2023-06-22 11:40:39	389	4

Dashboard

- Telemetry
- Upload/download/command planning



Terminal console commands execution

```
vcom:21> gs on 1
vcom:21> ping 1
Ping node 1, timeout 3000 ms, size 1 B: Reply in 9 ms
vcom:21> uptime 1
Uptime of node 1 is 166109 s
```

Onboard commands execution

```
2023-06-18 19:00:00 gs on 1
2023-06-18 19:00:02 a go
2023-06-18 23:00:00 a stop
2023-06-18 23:00:05 a pwm setv 0 0 0 200
```

VZLUSAT-2 telemetry via SatNOGS



- Open Source global network of satellite ground-stations (only receiving)
- We run our station with rotator: [VZLU-PRG](#)
- [VZLUSAT-2 dashboard](#) →
- Statistics
 - Power
 - Temperatures
 - Radio
 - Reboot count of OBC
- Radio statistics
 - Sent ~6 million packets
 - Received ~500 000



Earth observation – commanding



ADCS (attitude control) – crucial part for pointing

- MicroPython – control algorithm updated in-orbit
`> upy run 4 -a 3045`

Camera commanding

- FTP-like service, e.g. bash script / executable upload
`vcom> ftp up /tmp/ez.txz -r /sf/ez.txz`
Upload file: /tmp/ez.txz to /sf/ez.txz, backend=3
File size is 111592, checksum is 0xfd545a9d

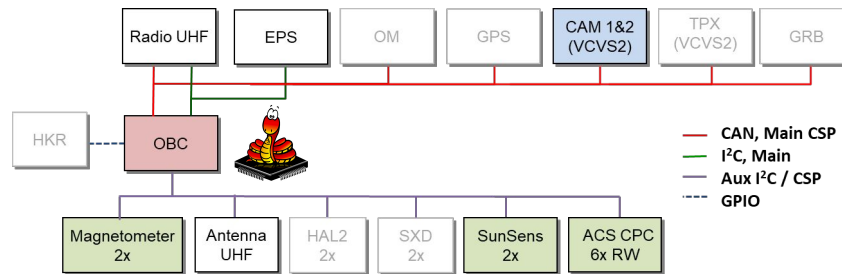
```
Transfer Status: 2686 of 2790 (96.27%)
100.0% [#####] 0.029 kB/s eta 2s
CRC Remote: 0xfd545a9d, Local: 0xfd545a9d
Uploaded 111592 bytes in 230364 ms (0.484 KBytes/sec)
```

- CSP service command set (e.g., ping, uptime)

```
vcom> uptime 18
Uptime of node 18 is 10343 s
```

- RSH-like CSP command (e.g., console access),
buffer limited to 200 characters (popen/fgets)

```
vcom> rsh 18 "uptime"
rv=0,reply_len=63
02:52:33 up 2:52, 0 users, load average: 0.04, 0.01, 0.00
```



Earth observation – data collection



Raw ADCS data
Camera metadata
(1-2 passes)

```
Data chunk id=17134, time=2022-10-10 09:26:59, flag=0x0
0 : 2a d5 f9 23 00 d2 01 00 00 00 00 00 00 00 00 00 |*..#.....|
16 : 00 00 00 00 01 c0 df 7b c0 c3 c9 af 91 42 d3 3d |.....{.....B.=|
0 : 8e 01 be 7a 8a dc 3e ec 0b 98 3e b5 88 f2 2e 00 |...Z..>..K..>...|
16 : 00 00 ba 90 9c a2 00 00 00 00 00 00 00 00 00 00 |.....|
0 : 00 00 00 00 00 00 bf 80 00 00 bf 80 00 00 bf 80 |.....|
16 : 00 00 7f c0 00 00 7f c0 00 00 7f c0 00 00 7f c0 |...B...>!.2*..n.z|
0 : 00 00 bd 42 f3 0c 3e 21 17 32 3d e0 1d 0e bf 7a |...B...>!.2*..n.z|
16 : c5 ec 00 00 00 00 00 00 00 00 00 00 00 00 3f 80 |.....?..|
0 : 00 00 |...|
```

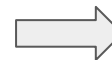
```
Data chunk id=17135, time=2022-10-10 09:27:01, flag=0x0
0 : 2a d5 f9 25 00 d2 02 00 00 00 00 00 00 00 00 00 |*..%.....|
16 : 00 00 00 00 01 c1 56 24 48 c3 c9 8d 0e 42 ce 70 |.....V$H...nB.p|
0 : c1 01 be 87 d2 16 3e fa 7c 78 3e b2 04 ba ae 40 |.....>..|X>....|
```

Automation in
CI/CD pipeline



Upload camera
command set (1 pass)

- Compression
- Save thumbnail to OBC storage



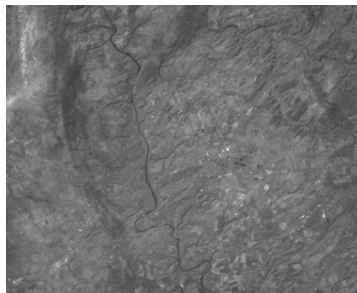
Collect all image data
(35-40 passes)

Upload camera
command set (1 pass)

- Save full image to OBC storage



Thumbnail



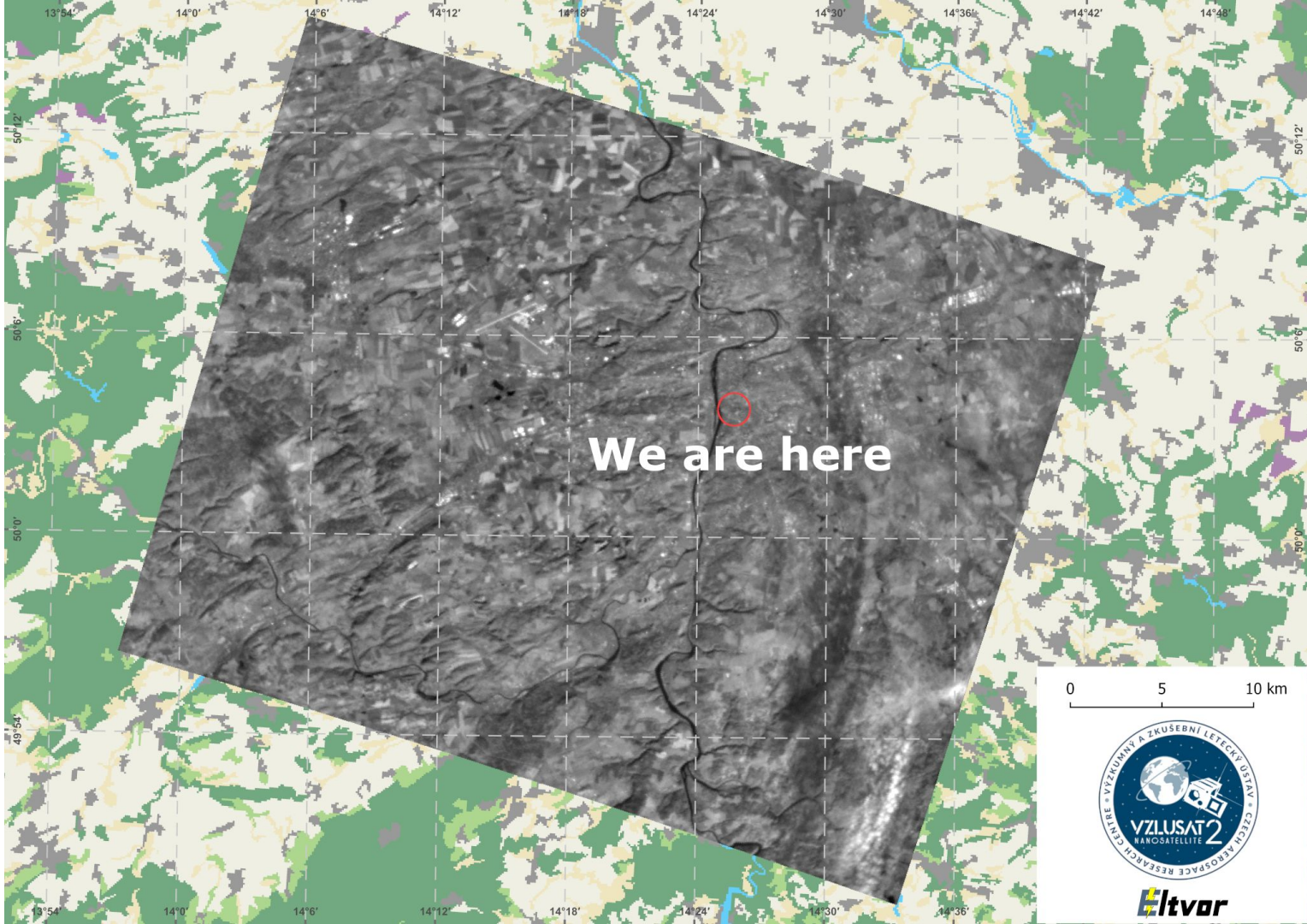
Collect all
thumbnail data
(1-2 passes)



Raw thumbnail data

```
Data chunk id=2, time=2022-10-11 18:47:14, flag=0x0
0 : 30 30 30 30 38 30 3a 2f 32 51 41 4a 51 41 42 51 |000080:/2QAJQABQ|
16 : 33 4a 0c 59 58 52 6c 5a 43 42 69 65 53 42 50 63 |3JLYXR1ZCbieSBPc|
0 : 47 56 75 53 6c 42 46 52 79 42 32 5a 58 4a 7a 61 |6VuSLBFRyB22XJza|
16 : 57 39 75 49 44 49 75 4d 79 34 78 2f 35 41 41 43 |W9uIDIuMy4x/SAAC|
0 : 67 41 41 41 41 44 4a 77 67 41 42 2f 35 50 66 66 |gAAAAADJwgAB/SPff|
16 : 36 4a 41 63 76 57 52 69 6f 45 42 48 49 31 6c 66 |6JAcvWR1oEBHI1lf|
0 : 6e 52 6b 4e 6d 59 6c 64 75 6c 33 69 62 79 63 39 |nRkNmYlduL3ibyc9|
16 : 64 6b 3d |dk=|
```

```
Data chunk id=3, time=2022-10-11 18:47:14, flag=0x0
0 : 30 30 30 31 36 30 3a 51 6f 66 32 59 6d 36 38 59 |000160:Qof2Ym68Y|
16 : 56 4c 70 30 50 37 75 30 52 5a 54 69 41 51 65 6b |VLp0P7u0RZT1AQek|
0 : 75 4d 6d 58 78 61 43 39 4a 4d 6c 62 52 52 2f 6a |uMmXxaC9JMLbRR/j|
```



Eltvar

Conclusion and future plans



- Do we plan further missions with Linux? Yes, we do.
 - The goals were met
 - Linux is working well in space
 - Many features readily available (e.g., libraries, protocols, drivers)
- New computer is under development
 - It extends the functionality, e.g.:
 - More interfaces
 - Bigger storage
 - Supervisor
 - Basic bring-up is done
 - Cooperation with [Linux4Space](#)

